The benefit of supplementary text for the resolution of auditory overload

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Abstract

This research determined whether the provision of supplementary text would help resolve the problem of auditory overload during military command and control operations. Listeners, twenty-four English-fluent, normal-hearing, males and females, were presented one block of 78 triads of simultaneous messages over a communication headset, under each of twelve listening conditions. The messages were recordings made by two males (left and right ears, respectively) and a female. Listening conditions were defined by combinations of the background (quiet or vehicle noise), ear assignment of the female talker (right or left ear), and the provision of supplementary text (none, random but equally likely across the three talkers or associated with one of the three talkers). Using a computer keypad, listeners encoded only those messages which began with a pre-assigned call sign. These occurred once during 27 of the 78 triads, nine from each of the three talkers. The overall mean percentage of correct responses was 78%. Male and female listeners performed similarly and were equally intelligible as talkers. There was a significant right ear advantage for discriminating among talkers. Provision of text resulted in an increase in the percentage correct of 10–26% that did not compromise understanding of unaccompanied target messages.

Significance to defence and security

Auditory overload, the problem of competing messages, is particularly challenging in military command and control where operators may be tasked with monitoring, responding to and relaying messages arriving concurrently over several networks associated with different levels of command. The task may be further complicated by the masking effect of background noise. This research showed that auditory overload may be resolved, in part, by providing supplementary text for one of the audio networks, without compromising the understanding of unaccompanied audio. Male and female listeners performed similarly and were equally intelligible. The finding of a right ear advantage suggests that higher priority messages should be delivered to the dominant right ear.

Résumé

Cette recherche a permis de déterminer si l'ajout de texte supplémentaire pouvait régler le problème de surcharge auditive pendant les opérations militaires de commandement et contrôle. Les auditeurs, 24 hommes et femmes parlant couramment l'anglais et possédant une audition normale, ont été soumis à une série de 78 blocs de trois messages simultanés, transmis à un casque d'écoute, dans chacune des douze conditions d'écoute. Les messages avaient été enregistrés par deux hommes (oreille gauche et oreille droite, respectivement) et une femme. Les conditions d'écoute étaient définies selon une combinaison de bruits de fond (silence ou bruits de véhicules), d'assignation de l'interlocuteur féminin (oreille droite ou gauche) et d'ajout de texte supplémentaire ou non (aucun, aléatoire mais pouvant provenir tout aussi bien de l'un des trois interlocuteurs ou associé à l'un des trois interlocuteurs). À l'aide d'un clavier numérique, les auditeurs ont encodé uniquement les messages qui débutaient par un indicatif préétabli. Ces indicatifs, donnés neuf fois par chacun des interlocuteurs, précédaient 27 des 78 blocs de trois messages. Le pourcentage moyen global de réponses correctes était de 78%. Les auditeurs masculins et féminins ont eu des résultats semblables, et étaient aussi intelligibles que les interlocuteurs. Il y avait une forte dominance de l'oreille droite pour la différenciation entre les interlocuteurs. L'ajout de texte supplémentaire a produit une augmentation du pourcentage de 10 à 26% de réponses correctes, sans nuire à la compréhension des messages cibles qui n'étaient pas accompagnés.

Importance pour la défense et la sécurité

La surcharge auditive, un problème de messages concurrents, est particulièrement présente dans les situations militaires de commandement et contrôle, où l'on demande aux opérateurs de surveiller les messages qui entrent en même temps sur les nombreux réseaux liés aux différents échelons de commandement, d'y répondre et de les relayer. Cette tâche peut être davantage compliquée par l'effet masquant des bruits de fond. Cette recherche a démontré que la surcharge auditive pouvait être corrigée en partie par l'ajout de texte à l'un des réseaux audio, sans nuire à la compréhension des messages audio non accompagnés. Les auditeurs masculins et féminins ont eu des résultats semblables et étaient tout autant intelligibles. La constatation d'une dominance de l'oreille droite laisse croire que les messages prioritaires devraient être transmis à l'oreille droite dominante.

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1 Introduction

The intent of this research was to determine whether the provision of supplementary text would help to resolve the problem of auditory overload during military command and control operations. Auditory overload refers to a situation in which military members (e.g., radio operators) are required to monitor, transcribe, respond to and relay orders or strategic information delivered simultaneously over two or more audio networks or channels. Audio channels may be associated with different levels of command or units within a battle space. The possible benefit of a text message in addition to the audio for one of a triad of simultaneous messages presented over a communication headset in vehicle noise was explored.

Previous studies have documented enhanced speech recognition with auditory-visual (AV) speech, compared with either auditory (A) or visual (V) presentation alone (e.g., Grant et al., 1998; Grant and Seitz, 1998), as well as the benefits of multi-modal communications (Finomore et al., 2010). For example, Grant et al. (1998) tested participants with various degrees of noise-induced hearing loss on their ability to recognize consonants and sentences presented either binaurally over a headset at a comfortable listening level, on a video monitor or by means of both modes of communication simultaneously. Items were presented in a background of speech-spectrum shaped noise at a speech-to-noise ratio (SNR) of 0 dB. All the participants showed an AV benefit for both types of speech materials. In the case of consonants, AV recognition scores ranged from 60–90%, compared with 20–74% for A and 21–40% for V presentations. The pattern of outcomes was the same for the sentences. AV presentations resulted in recognition scores of 23–94%, compared with A scores of 5–70% and V scores of 0–20%.

Using a different paradigm that modelled listening in a military operational environment, Finomore et al. (2010) investigated the benefits of a multi-modal communications (MMC) suite that incorporated a standard radio, 3-D audio, a repeat function, and text-based messaging (chat). The MMC suite was compared with each of monaural radio communications, 3D audio, and chat for detecting and replying to target messages delivered over several channels, over a 27-minute session. Listeners pressed a push-to-talk button to signify the active channel and repeated back the message they heard. Target message detection and verbal response accuracy were significantly greater with MMC and chat than with either 3D audio or the standard radio. In contrast, detection response times were faster for 3D audio and the standard radio.

More recently, Abel et al. (2012, 2014) assessed the benefit of providing visual cues for communication in a mock-up of the crew compartment of a mobile command post. In the first of two studies, Abel et al. (2012) presented sets of concurrent diotic (same) or dichotic (different) messages over the right and left earphones of a communication headset and a different message over a four-speaker array surrounding the head, in quiet or in a background of either noise recorded in a land vehicle driving along a highway (Bison noise), speech babble noise or both. Speech babble simulated irrelevant conversation in close proximity. The at-ear SNRs for messages presented over the headset and loudspeakers were 0 dB (babble noise) and 5 dB (Bison noise). Using a computer keypad, normal-hearing, English-fluent, listeners encoded words contained only in messages beginning with a pre-assigned call sign. They achieved close to 100% correct for the headset messages, either in quiet or noise, and for the loudspeaker messages, in quiet. The percentage correct was significantly less by 30–35% when messages were presented over the loudspeakers in the Bison noise. Adding the babble noise decreased the loudspeaker percentage correct by an additional 12%. A visual icon on the listener's computer monitor directing attention to the source of incoming target messages significantly increased the percentage correct for the loudspeaker messages by 7%. This finding corroborates results reported by Best et al. (2007) that a vision cue signifying the location of a message and its time of occurrence will improve its identification.

In their second study, Abel et al. (2014) investigated the effect of replacing audio with either visual or audio-visual messages. Normal-hearing listeners completed two concurrent tasks, again either in quiet or in the Bison noise. For Task 1 they were presented dichotic pairs of messages with simultaneous onsets over right and left earphones of a communication headset. As for the first experiment, they encoded only those messages beginning with a pre-assigned target call sign. For Task 2 they used the computer keyboard to agree or disagree with the correctness of simple mathematical equations (e.g., 4+1=5) which occurred randomly during headset message pairs that did not contain a target. The equations were presented either (1) over the four-speaker array surrounding the head, (2) as text on the laptop monitor, (3) in both the audio and visual modalities simultaneously or (4) not at all. The tasks were of equal importance. Listeners achieved an average mean score of at least 78% correct for dichotic phrases presented over the headset in Task 1. Averaged across experimental conditions, there was a significant right ear advantage of 7%. The right ear advantage was particularly apparent in the noise background, where the interaural difference was 12%. For Task 2, accuracy was significantly better by 20% when the equations were presented visually or audio-visually. These findings point to the importance of delivering higher priority communications to the dominant (right) ear, and the advantage of using text as an adjunct to audio messaging.

2 Purpose

The present experiment was a follow-on to the work previously reported by Abel et al. (2012, 2014). In the two previous studies, it was found that listeners had relatively little difficulty discriminating between and understanding a pair of messages delivered simultaneously to the two ears over a communication headset in background noise. Loudspeaker messages were more difficult to understand, likely because they had to cross the headset barrier which may have altered their spectra. Performance improved significantly if a visual icon directed attention to the active channel or the audio was accompanied by text. Questions of interest for the present study were if, and the degree to which, the understanding of headset messages would deteriorate if another talker was added to the mix, in one or other ear, and whether the addition of text for one of the talkers would be beneficial or detrimental. Several other issues were addressed, in part to confirm previous findings, and in part because they had not been applied to communicators (e.g., radio operators) in military operational environments who are subject to auditory overload (Abel, 2008). These were: (1) Do male and female listeners differ in their ability to understand speech? (Markham and Hazan, 2004), (2) Does the presence of noise exacerbate auditory overload? (Abel et al., 2012), (3) Is there an advantage to presenting target messages to either the left or the right ear during multiple simultaneous presentations? (Kimura, 2011), (4) Are male and female talkers equally intelligible? (Ellis et al., 1996), (5) Does the addition of text improve understanding, compared with audio presentation alone, when there are multiple talkers using the same modality? (Abel et al., 2014), (6) Is there an advantage to pairing text with a selected talker or is it as likely to be advantageous if randomly paired with messages across talkers?, and (7) If supplementary text aids understanding, does it occur at the expense of understanding audio traffic that is not accompanied by text? The last two questions have not been previously addressed.

3 Methods and materials

3.1 Participants

Twenty-four participants, twelve males (aged 26–41 years) and twelve females (aged 19–48 years), with normal hearing thresholds no greater than 15 dB HL (decibels, hearing level) bilaterally at the speech frequencies, 0.5, 1, 2 and 4 kHz (Yantis, 1985) were recruited to serve as listeners by means of an email sent to employees of military units in the Toronto area. Sixteen were serving members of the Canadian Armed Forces (CAF) and had some prior experience communicating over tactical headsets. The remaining eight were civilians with limited experience with the use of such devices. Since the listeners would be tested in a sound proof room for an extended period of time with auditory materials, they were screened for a history of claustrophobia, the use of medications that might affect the ability to complete the study, and ear disease, including excess wax build up, hearing loss and tinnitus. Other exclusion criteria included the inability to read instructions on a laptop monitor at the test distance without the use of corrective glasses. Glasses have been shown to interfere with the fit of muff-style devices of the type that would be used in the study (Abel et al., 2002). To control for the effect of fluency on speech understanding, all were required to be proficient in speaking and understanding English, the test language (van Wijngaarden et al., 2002). Only those whose native language was English or those who had learned English before the age of 12 years were considered for the study (Mayo et al., 1977). They were also required to obtain a score of at least 85% on an adapted timed (20 minutes) paper and pencil version of a test by The Skylark School of English (Skylark School, 2012). All but three reported that they were right-handed and thus likely left hemisphere/right ear dominant (Foundas et al., 2006; Kimura, 2011). One of the three left handers volunteered that previous tests had confirmed that he was left hemisphere dominant.

3.2 Apparatus

The test facility has been described previously (Abel et al., 2012). Listeners were tested individually while seated in front of a laptop computer in a mock-up of a CAF land vehicle, the Bison Command, Control, Communications and Intelligence mobile command post (Bison C3I MCP), in our centre's Noise Simulation Facility (NSF). The NSF is a semi-reverberant room, 10.55 metres (L) by 6.10 metres (W) by 3.05 metres (H). An array of loudspeakers comprising four low-frequency drivers (Bass Tech 7; ServoDrive Inc., Glenview, Illinois), eight mid-frequency drivers (Gane G218; Equity Sound Investments Inc., Bloomington, Indiana), and four high-frequency drivers (DMC 1152A; Electro-Voice, Burnsville, Minnesota) occupies the width of the shorter rear wall. These are powered by fourteen amplifiers (8 stereo model 4B and 6 mono model 7B; Bryston Ltd., Peterborough, Ontario). This array allows the acoustic simulation of a wide range of CAF environments, in terms of both level and energy spectrum, and is capable of producing levels in excess of 130 dB SPL (decibels, sound pressure level). The background noise in this facility is 28 dB SPL.

All the listeners were fitted with a communication headset (Racal Slimgard II RA108; Esterline Technologies Corp, Bellevue, Washington). The Racal headset is currently used by CAF personnel operating land vehicles.

3.3 Experimental design

Each listener completed a task under twelve different listening conditions. The task involved listening to triads of messages with simultaneous onsets, presented over the communication headset. The messages were spoken by two male talkers, one assigned to the right ear (MR), one assigned to the left ear (ML) and a female talker (F). The listening conditions were defined by combinations of the background (quiet or Bison noise—the continuous playback through the loudspeakers of a digital recording of noise heard within a Bison C3I MCP being driven along a highway), the ear assignment of the female talker (right or left) and the availability of supplementary text for a subset of target messages (none - N, random but equally likely across the three talkers - RA, or associated with the messages spoken by one of the three talkers - AT). In the case of the third text option, the twenty-four listeners were divided into three subgroups of eight, for whom the text was associated with the target messages spoken by only one of the three talkers, ML, MR or F, respectively. These subgroups were labelled ATML (associated text male left), ATMR (associated text male right) and ATF (associated text female). This measure was instituted to reduce the number of listening conditions within listener. The subgroups were comprised of four males and four females, selected randomly from the total group. The full list of the independent and dependent variables, along with acronyms associated with levels of each, is given in Table 1.

The messages were taken from the Coordinate Response Measure (CRM), a non-standardized speech corpus for multi-talker communications research, adapted by Bolia et al. (2000) to measure speech intelligibility in military environments. Each message in the corpus consists of a recording of a talker speaking a call sign following by a colour-number combination within a carrier phrase, (e.g., "**Baron** go to **Blue Five** now"). In all, there are 256 messages in the corpus, made up of combinations of eight call signs (Charlie, Ringo, Laker, Hopper, Arrow, Tiger, Eagle and Baron), four colours (blue, red, white and green) and eight numbers (1, 2, 3, 4, 5, 6, 7, and 8). Recorded lists spoken by four male and four female talkers are available. For the present study, the lists spoken by two of the males and one of the females were used to maximize the distinction across messages within a triad. Messages in the corpus for each of the three talkers were digitally stored as a single file on a computer hard drive, with the carrier words removed. The duration of each three-word message was approximately three seconds.

Seventy-eight triads of messages were presented in each condition. The number of triads was constrained by the requirement to complete the experiment with instructions, practice and debriefing in two two-hour sessions. Listeners were instructed to respond only to those messages which began with a pre-assigned call sign (the target messages). All were assigned Baron as their call sign. In a previous study, statistically significant differences in outcome were observed for target messages beginning with Baron and Charlie, favouring Baron, in spite of similarities in the levels and spectra of the messages they began (Abel et al, 2014). The difference in outcome may have been due to voicing (Dubno et al., 1981). Baron begins with a voiced consonant and Charlie with a voiceless consonant. In the present experiment, non-target messages began with the call sign Ringo. Baron and Ringo are two of three possible alternatives (Baron, Ringo and Laker) in the call sign set that begin with voiced consonants. Published studies have shown that consonant-vowel-consonant words (CVCs) beginning with "b" are less likely to be confused with CVCs beginning with "r" than with "l" (Woods et al, 2010).

The target call sign (Baron) began one of the three messages (the target messages) on 27 of the 78 triads (34.6% probability of occurrence), nine for each of the three talkers. The probability of target messages is in line with the probability of occurrence of critical signals in vigilance experiments (for a review see Abel, 2009). For the no text condition, none of the 27 target messages was accompanied by text. In the random text condition, text accompanied three of the nine messages spoken by each of the three talkers, randomly determined. For the one talker text condition all nine target messages from one of the talkers were accompanied by text. As noted above, the selected target talker was counterbalanced across listeners, with subgroups of eight assigned one of the three, respectively. A target message could be spoken by only one of the talkers during any triad, and never twice in succession by the same talker. It should be noted that text only accompanied target messages. For both target and non-target triads, the assignment of the 32 possible colour-number pairings was random with the restriction that a particular colour-number pairing could only occur once within a triad. Except for these restrictions, they were selected randomly and independently for each listener.

The target messages were presented at an at-ear level of 70 dB SPL and the non-target messages at an at-ear level of 67 dB SPL. Intensity differences between talkers have been shown to aid differentiation (Drullman and Bronkhorst, 2004). For the Bison noise conditions, a digital recording was played over the loudspeaker array in the test room (outside the mock-up of Bison C3I MCP) at an at-ear level under the headset of 65 dBA (decibels, A-weighted). At source the level was 95 dBA which is about 5 dB lower than the level measured inside a light armoured vehicle driving along a highway (Nakashima et al., 2007). The at-ear SNRs, 2–5 dB, have previously been shown to result in speech understanding for single talkers in the range of 60–80% (Abel et al., 1990).

The listener was instructed to respond to a target message by pressing four responses keys, in order, on a standard laptop computer keyboard. These were coded for the perceived ear (one of two labeled keys), the talker's gender (one of two labeled keys), the colour (one of four labeled keys) and the number (one of eight labeled keys), respectively. The keys for each of these attributes of the message were located centrally on different rows of the keyboard. No feedback was given about the correctness of the responses. The rate of presentation of triads, one every seven seconds, was controlled by computer program. Pilot testing confirmed that the messages could be heard distinctly and that listeners had adequate time to respond. It took 15 minutes to present each condition, including the time to inform listeners of the upcoming condition. The twelve conditions were presented in two sets of six, one set for the quiet background conditions and one set for the Bison noise background conditions, during two consecutive sessions that were no more than one week apart. The order of the backgrounds was counterbalanced within male and female listener subgroups.

In the text conditions, the components of the selected target messages (e.g., "Right Male Blue Five") were presented vertically on four separate lines, centred on the monitor of a standard laptop computer, in Times New Roman 14 point font. Text and audio onsets were simultaneous. However, the text was approximately one-third second longer than the audio to allow sufficient time to be read (Abel, 2014).

Table 1: The independent and dependent variables.

INDEPENDENT VARIABLES

A. <u>Within Subjects</u>:

Background	- quiet or Bison noise
Ear assignment for the female talker	- female left (FL) or female right (FR)
Text	- none (N), random (RA), or associated with a particular talker (AT)
Target Talker	- male left (ML), male right (MR), female (F)

B. <u>Between Subjects</u>:

Gender of Listeners	- males (N=12) and females (N=12)
Job Type	- military (N=16) and civilian (N=8)
Order of Backgrounds	- quiet first (N=12) and Bison noise first (N=12)
Associated Text	- associated text, male left (ATML, N=8), associated text, male right (ATMR, N=8), associated text, female (ATF, N=8)

DEPENDENT VARIABLES

Percentage of hits – correct report of the target message: ear, gender of the talker, colour and number for the 27 target messages beginning with the call sign Baron
Percentage correct reports of the ear to which the target message was sent
Percentage correct reports of the gender of the talker of the target message
Percentage correct reports of the colour component of the target message
Percentage correct reports of the number component of the target message
Percentage of misses, i.e., not responding to a target message
Percentage of false alarms, i.e., responding to any of the messages in the 51 triads in which there was no target message

3.4 Procedure

The protocol was approved by the Defence Research and Development Canada Human Research Ethics Committee (DRDC HREC). Volunteers were asked to review an information sheet and sign a consent form prior to participation. At the start of each session, they were fitted with the headset by a trained technician. They were then presented a sample of the Bison noise, listened to audio and visualized text on the laptop monitor for sample messages, and practiced responding. Feedback was given for the practice but not for the experimental trials. Before each block of 78 triads, listeners were informed of the details of the upcoming condition on the laptop they used for responding. They were instructed that they were permitted to use either or both hands for responding. Short breaks separated the six conditions presented during a session. The total duration of each of the two experimental sessions, including the time for instructions, practice, breaks and debriefing was two hours.

4 Results

The mean percentages and associated standard deviations, across listeners, for hits, i.e., correctly reporting all of the ear, gender, colour and number for the target messages, are presented in Table 2, for combinations of the background (quiet or Bison noise), the ear assignment of the female talker (female left, FL or female right, FR), the text condition (no text, N; random text, RA; or text associated with a talker, AT) and the target talker. With respect to the last of the text options, results are also presented separately for the three subgroups of eight listeners, ATML, ATMR and ATF, for whom the text was specifically associated with one of the three talkers, ML, MR and F, respectively. The overall mean percentage of hits, averaged across conditions, was 77.5%.

A repeated measures analysis of variance (ANOVA; Daniel, 1983) was applied to the percentage of hits obtained from all twenty-four listeners for combinations of conditions defined by the background, ear of the female talker (FL and FR), text condition (N, RA and AT), and target talker (ML MR and F), with gender as the between subjects factor. The analysis showed that the gender of listeners and the text condition were not significant factors. There were statistically significant effects of the background ($F_{1,22}$=4.78; $p<0.04$), target talker ($F_{2,44}$=7.28; $p<0.002$), ear assignment of the female talker by target talker ($F_{2,44}$=15.65; $p<0.0001$), and background by ear assignment of the female talker by target talker ($F_{2,44}$=4.66; $p<0.01$). An unexpected finding was that listeners' percentage of hits was significantly higher in the Bison noise than in quiet by 6.6% (80.8% vs 74.2%). Post hoc pairwise comparisons using Fisher's Least Significant Difference (LSD) test ($\alpha = 0.05$) (Daniel, 1983) showed that, in the case of the main effect for the target talker, the percentage of hits for MR (85.8%) was significantly higher than that for either ML (73.8%) or F (73.0%) who were no different from each other. However, as shown in Figure 1, this outcome was dependent on the ear assignment of F. When the female talker was assigned to the left ear, the mean score was significantly higher for MR (93.1%) than for either ML or F who were not different (66.8% and 69.0%, respectively). In contrast, when the female talker was assigned to the right ear, there were no differences among the three talkers. Scores ranged from 76.9% to 80.7%. The score for the female target talker was relatively higher but only borderline statistically significant when she was assigned to the right ear compared with left ear (76.9% vs 69.0%).

Repeated measures ANOVAs, with gender as the between subjects factor, were also carried out for the percentages correct for each of the target message ear, gender, colour and number, taken separately. The observed overall means were 90.9%, 90.4%, 82.3% and 85.5%, respectively. The pattern of results was similar to that observed for the percentage of hits, i.e., correct report of all ear, gender, colour and number. Statistically significant outcomes of the repeated measured ANOVAs are listed in Table 3. For each of the four elements of the report, there were significant effects of the background and interaction of the ear assignment of the female talker by target talker. In the case of the percentage correct ear reports, there was also a significant three-way interaction of the ear assignment of the female talker by text condition by target talker ($F_{4,88}$=3.09; $p<0.02$). Follow up post hoc pairwise comparisons using Fisher's LSD test ($\alpha = 0.05$) indicated that within the ear assignment of the female talker, the differences among the three text conditions (N, RA, and AT) did not reach statistical significance for any of the three target talkers.

Table 2: The percentage of hits (correct ear, gender, colour and number) for combinations of the background, ear assignment of the female talker, text condition, and target talker.

		Background/Female Ear Assignment			
		Quiet		Bison Noise	
Text Condition/ Talker	N	Female Left	Female Right	Female Left	Female Right
<u>No Text</u>	24				
Male Left		54.3 (35.9)*	76.8 (29.5)	70.4 (29.6)	79.2 (27.3)
Male Right		95.2 (9.5)	68.1 (32.0)	96.0 (6.6)	85.0 (19.8)
Female		65.4 (31.6)	73.5 (20.6)	71.8 (27.1)	77.6 (15.6)
Total		71.4 (15.9)	72.8 (19.4)	79.3 (17.3)	80.6 (14.7)
<u>Random Text</u>	24				
Male Left		64.3 (29.5)	84.3 (19.2)	70.8 (27.7)	79.1 (24.5)
Male Right		88.1 (18.6)	74.1 (29.7)	93.8 (13.3)	85.8 (22.4)
Female		66.2 (30.7)	75.9 (21.4)	72.7 (29.4)	83.7 (15.5)
Total		72.8 (16.4)	78.1 (16.2)	79.0 (20.4)	82.8 (13.8)
<u>Assoc Text</u>	24				
Male Left		66.3 (36.2)	81.2 (27.3)	75.0 (31.7)	83.4 (23.7)
Male Right		92.4 (15.8)	72.8 (31.4)	93.3 (14.4)	84.8 (22.9)
Female		64.9 (35.4)	71.8 (30.1)	73.2 (28.0)	79.0 (17.3)
Total		74.6 (16.4)	75.2 (19.0)	80.3 (13.2)	82.3 (12.0)
<u>Assoc Text, Male Left</u>	8				
Male Left		94.3 (12.2)	95.6 (8.6)	94.0 (6.4)	91.5 (16.8)
Male Right		81.6 (23.2)	67.4 (24.6)	87.4 (23.6)	82.8 (18.9)
Female		58.0 (40.9)	75.9 (22.6)	59.3 (35.4)	80.0 (17.7)
Total		77.9 (18.1)	79.8 (10.6)	80.0 (14.9)	84.8 (12.7)
<u>Assoc Text, Male Right</u>	8				
Male Left		59.1 (37.6)	72.0 (36.2)	77.0 (17.6)	84.3 (17.0)
Male Right		97.1 (8.1)	81.8 (35.1)	97.0 (5.6)	92.8 (12.1)
Female		58.0 (37.8)	57.8 (29.8)	73.3 (25.4)	77.1 (17.8)
Total		71.5 (16.3)	70.4 (20.0)	82.4 (11.5)	84.5 (9.5)
<u>Assoc Text, Female</u>	8				
Male Left		45.4 (36.0)	76.0 (26.3)	54.0 (45.0)	74.5 (33.3)
Male Right		98.5 (4.2)	69.1 (35.5)	95.5 (6.2)	78.8 (33.2)
Female		78.8 (26.3)	81.9 (34.7)	87.0 (15.3)	80.0 (18.7)
Total		74.0 (16.3)	75.5 (24.9)	78.6 (14.4)	77.8 (13.6)

*Mean (standard deviation)

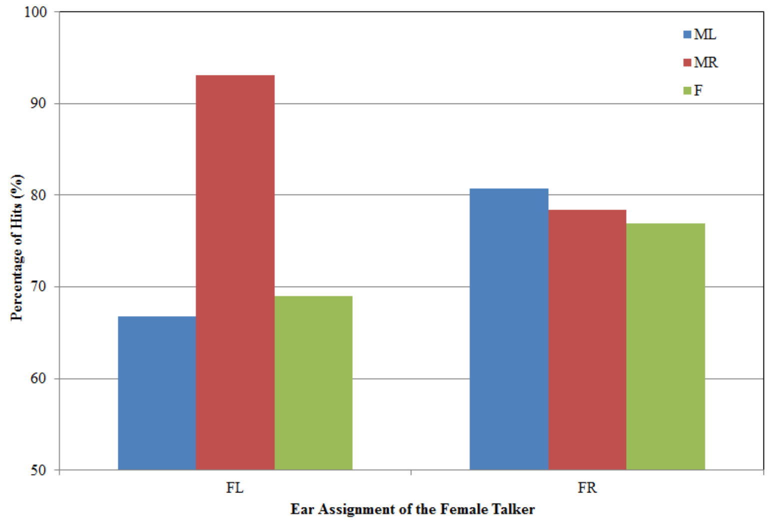

Figure 1: The interaction of the ear assignment of the female talker and the target talker on the percentage of hits (N=24).

Table 3: Summary of statistically significant outcomes for the repeated measures ANOVAs on the percentage of hits and the percentages correct for each of ear, gender, colour and number.

Analysis	Significant Outcome	F	p<
Hits	Background	4.79	0.04
	Target Talker	7.28	0.002
	Female Ear by Target Talker	15.65	0.0001
	Background by Female Ear by Target Talker	4.66	0.01
Ear	Background	11.31	0.003
	Female Ear by Target Talker	7.58	0.003
	Female Ear by Text Condition by Target Talker	3.09	0.02
Gender	Background	15.42	0.001
	Female Ear	6.81	0.02
	Target Talker	3.12	0.05
	Female Ear by Target Talker	8.72	0.001
	Background by Female Ear by Target Talker	5.88	0.005
Colour	Background	7.66	0.01
	Target Talker	8.46	0.001
	Female Ear by Target Talker	15.91	0.001
	Background by Female Ear by Target Talker	5.21	0.01
Number	Background	11.16	0.003
	Target Talker	3.39	0.04
	Female Ear by Target Talker	10.59	0.0001
	Background by Female Ear by Target Talker	4.12	0.02

4.1 The effect of background

In order to shed light on the statistically significant beneficial effect of the Bison noise compared with quiet, a repeated measures ANOVA was applied to the percentage of hits, with order of the two backgrounds (quiet conditions first versus Bison noise conditions first) as the between subjects factor rather than gender. The results showed statistically significant effects of the background ($F_{1,22}$=9.52; p<0.005), target talker ($F_{2,44}$=7.41; p<0.002), background by order ($F_{1,22}$=22.71; p<0.0001), ear assignment of the female talker by target talker ($F_{2,44}$=14.75; p<0.0001), background by ear assignment of the female talker by target talker ($F_{2,44}$=5.34; p<0.008), and background by ear assignment of the female talker by target talker by order ($F_{2,44}$=3.34; p<0.04). The significant two-way interaction of background by order is displayed in Figure 2, averaged across the other variables. These data show that listeners' scores were relatively greater, on average, for the background condition that was presented second, regardless of whether it was the quiet or Bison noise, suggesting that practice was a possible determinant of outcome rather than a beneficial effect of the noise. Post hoc pairwise comparisons using Fisher's

LSD test (α<0.05) indicated that the percentage of hits for the quiet condition presented first was significantly less (67.9%) than the percentages of hits for the quiet condition presented second (80.5%), and the Bison noise condition presented first (76.9%) or second (84.7%) which were no different.

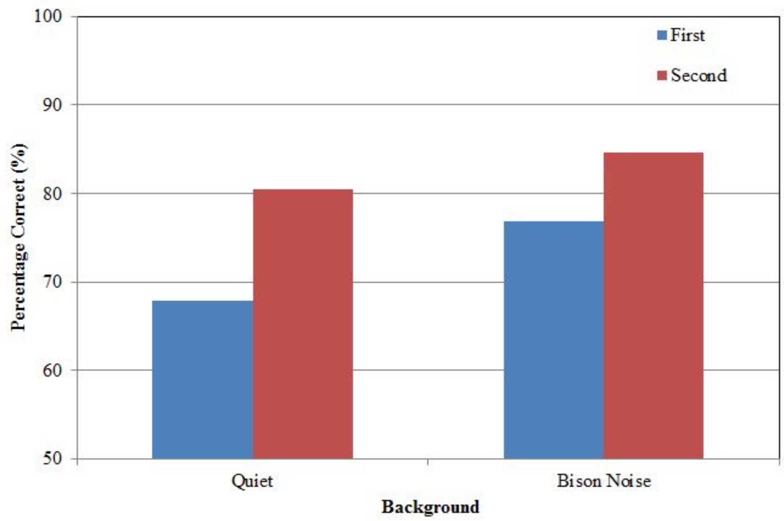

Figure 2: The effect of order of the quiet and Bison noise backgrounds on the percentage of hits (N=12).

4.2 Civilian versus military listeners

Sixteen of the listeners were military members and had some on-the-job training in radio communications. Eight were civilians whose only experience was previous participation in experiments involving auditory perception. Results for the two groups were compared using the nonparametric Independent-Samples Mann-Witney U test (Conover, 1980). The test was applied to the sum of the percentages of hits observed for all three talkers, for each of the twelve combinations of the background, ear assignment of the female talker and text (N, R and AT). In none of these twelve conditions was there a statistically significant difference between the military and civilian groups.

4.3 Associating text with a target talker

In previous ANOVAS, the three subgroups, (ATML, ATMR and ATF) for whom text associated with the male left (ML), male right (MR) or female (F) talker, respectively, were treated as one group of twenty-four listeners, all of whom completed the task with no text, random text or text associated with a talker. The results indicated that the text condition was not a significant factor. A subsequent repeated measures ANOVA was carried out comparing the effect of the text condition within each of the three associated text subgroups as the between subjects factor. The results showed that the three subgroups, ATML, ATMR and ATF, were not different as a main effect. There were statistically significant effects of the background ($F_{1,21}$=5.32; p<0.03), target talker ($F_{2,42}$=8.44; p<0.001), ear assignment of the female talker by target talker ($F_{2,42}$=15.22; p<0.0001), and background by ear assignment of the female talker by target talker ($F_{2,42}$=4.67; p<0.02), as in previous analyses, as well as the text condition by target talker by the associated text subgroup ($F_{8,84}$=3.84; p<0.001).

The significant three-way interaction, text condition by target talker by associated text subgroup, is displayed as two two-way interactions in Figures 3 and 4. Figure 3 compares the results for the three target talkers, ML, MR, and F within each of the three associated text subgroups, ATML, ATMR and ATF, averaged across the text condition. Figure 4 compares the three text conditions (none, random and associated) within each of the associated text subgroups, averaged across the target talker**.** With respect to the data in Figure 3, post hoc pairwise comparisons indicated that when ML was accompanied by text in subgroup ATML, the percentage of hits was significantly higher than when not accompanied (93.8% compared with 73.1% in the case of ATMR and 62.5% in the case of ATF). When MR was accompanied by text in subgroup ATMR, the percentage of hits was significantly higher than when not accompanied (92.2% compared with 79.8% in the case of ATML but similar at 85.5% in the case of ATF). When F was accompanied by text in subgroup ATF, the percentage of hits was relatively (but not significantly) greater than when not accompanied (81.9% compared with 68.3% and 66.5% in the cases of ATML and ATMR, respectively). In summary, the gain amounted to 26% for the male left target talker, 10% for the male right target talker and 15% for the female target talker. With respect to the data in Figure 4, within each of the three associated text subgroups, the percentage of hits was relatively higher when a particular talker was accompanied by text than in the no text and random text conditions. Differences ranged from 9–15%. Post hoc pairwise comparisons indicated that only in one instance did the difference reach statistical significance, the difference between no text and associated text for the female talker in the ATF subgroup.

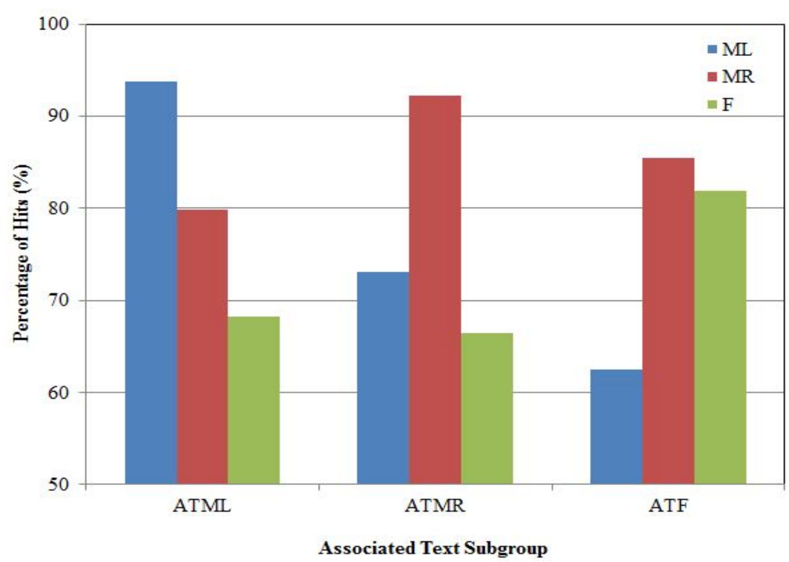

Figure 3: The effect of associated text on the percentage of hits for the three target talkers (N=8).

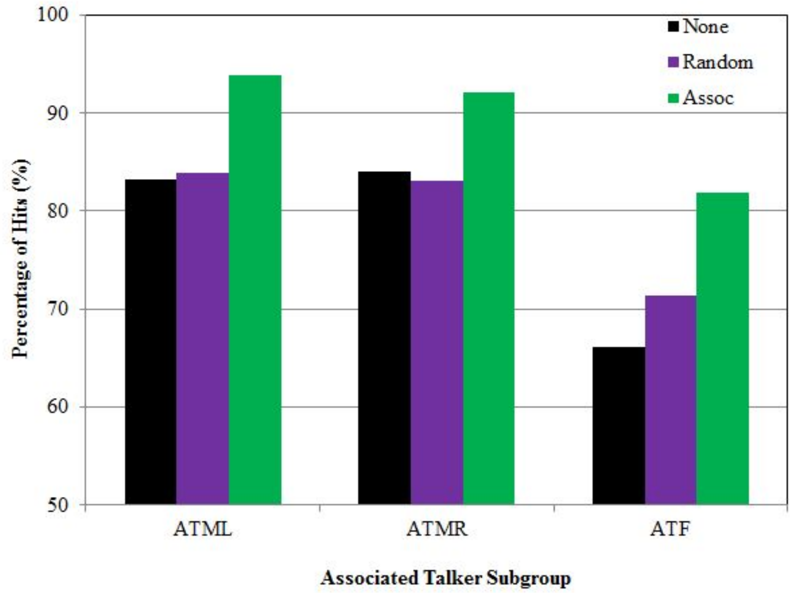

Figure 4: The effect of the text condition on the percentage of hits within each associated text subgroup (N=8).

4.4 The prevalence of false alarms and misses

Table 4 shows the percentage of false alarms, i.e., responding to a non-target message. For combinations of the background, ear assignment of the female talker and the text condition, these were no greater than 4%, averaged across listeners and talkers. Standard deviations associated with the means were no greater than 9%. The mean percentage of misses in each of the experimental conditions, averaged across listeners is shown in Table 5. Mean values were relatively low at 12% or less, except for four cases in the quiet condition when the female talker was assigned to the left ear (FL), and the talker was ML. These were the no text (17.9%), random text (13.8%), associated text male right (16.6%) and associated text female (17.9%) conditions. The standard deviations associated with these means were relatively high, ranging from 19.8% to 34.6%, compared with most of those observed for the other conditions. These data indicate that listeners had relatively little difficulty in discriminating target from non-target messages.

Table 4: The percentage of false alarms for the various listening conditions.

Text Condition	N	Quiet Female Left	Quiet Female Right	Bison Noise Female Left	Bison Noise Female Right
No Text	24	3.5 (9.0)*	3.4 (8.4)	2.0 (7.2)	0.8 (2.8)
Random Text	24	3.8 (6.3)	3.3 (8.7)	1.2 (3.6)	1.5 (6.7)
Assoc Text	24	2.1 (5.3)	2.8 (5.7)	1.6 (5.6)	1.2 (3.0)
Assoc Text, Male Left	8	1.1 (2.4)	4.0 (7.8)	1.6 (4.6)	0.9 (1.7)
Assoc Text, Male Right	8	1.3 (2.4)	1.9 (2.8)	0.0 (0.0)	1.0 (2.4)
Assoc Text, Female	8	3.9 (8.7)	2.4 (5.9)	3.1 (8.8)	1.6 (4.6)

*Mean (standard deviation)

Table 5: The percentage of misses for the various listening conditions.

		Background/Female Ear			
		Quiet		Bison Noise	
Text Condition/ Talker	N	Female Left	Female Right	Female Left	Female Right
No Text	24				
Male Left		17.9 (29.8)*	6.0 (16.8)	4.1 (13.7)	2.3 (11.2)
Male Right		0.0 (0.0)	4.1 (10.2)	0.0 (0.0)	0.5 (2.2)
Female		11.9 (15.5)	2.3 (4.6)	7.4 (22.1)	0.0 (0.0)
Total		9.8 (11.9)	3.9 (6.4)	3.7 (8.6)	0.9 (3.7)
Random Text	24				
Male Left		13.8 (19.8)	0.5 (2.2)	7.8 (17.6)	4.1 (15.8)
Male Right		0.5 (2.2)	1.4 (4.9)	0.9 (3.1)	0.9 (3.1)
Female		5.5 (9.2)	4.6 (11.7)	5.5 (16.2)	0.0 (0.0)
Total		6.4 (7.2)	2.0 (4.4)	4.6 (10.8)	1.6 (5.2)
Assoc Text	24				
Male Left		12.0 (25.5)	3.7 (9.5)	4.1 (12.9)	4.1 (18.0)
Male Right		0.5 (2.2)	3.2 (6.1)	0.5 (2.2)	0.9 (3.1)
Female		10.1 (15.5)	4.6 (14.1)	4.1 (7.8)	0.5 (2.2)
Total		7.2 (10.8)	3.6 (6.2)	2.7 (4.5)	1.7 (5.9)
Assoc Text, Male Left	8				
Male Left		1.4 (3.9)	1.4 (3.9)	0.0 (0.0)	0.0 (0.0)
Male Right		1.4 (3.9)	4.1 (8.2)	0.0 (0.0)	1.4 (3.9)
Female		9.6 (14.9)	0.0 (0.0)	8.3 (11.4)	0.0 (0.0)
Total		3.8 (4.8)	1.8 (3.9)	2.6 (3.6)	0.4 (1.1)
Assoc Text, Male Right	8				
Male Left		16.6 (34.6)	5.5 (15.6)	0.0 (0.0)	1.4 (3.9)
Male Right		0.0 (0.0)	2.8 (5.1)	0.0 (0.0)	0.0 (0.0)
Female		12.4 (18.1)	8.3 (19.3)	4.1 (5.7)	1.4 (3.9)
Total		9.4 (14.3)	5.1 (6.9)	1.1 (1.6)	0.8 (1.4)
Assoc Text, Female	8				
Male Left		17.9 (26.9)	4.1 (5.7)	12.4 (20.7)	11.0 (31.1)
Male Right		0.0 (0.0)	2.8 (5.1)	1.4 (3.9)	1.4 (3.9)
Female		8.3 (15.3)	5.5 (15.6)	0.0 (0.0)	0.0 (0.0)
Total		8.5 (11.8)	3.9 (7.5)	4.4 (6.7)	4.0 (10.2)

*Mean (standard deviation)

5 Discussion

Listeners in the present study had relatively little difficulty, on average, completing the auditory overload task. The overall mean percentage of hits (correct report of all of the ear and gender of the talker, along with the colour and number of the target message), averaged across the quiet and Bison noise backgrounds, ear assignment of the female talker, text condition and target talker was 78%. This outcome is in the range reported by Abel et al. (2014) for dichotic headset presentation of messages in quiet and Bison noise. Neither the gender nor the occupation (military or civilian) of the listeners were significant determinants of outcome. The outcomes for recorded male and female talkers were no different. These data suggest that there would be no advantage to recording warning messages in either a male or female voice for presentation over communication systems during military operations or for using gender as a selection criterion for operators.

The results of the present study are generally consistent with previous studies showing that gender is not a significant determinant of speech understanding (e.g., Ericson and McKinley, 1997; Ellis et al., 1996; Markham and Hazan, 2004). For example, Ellis et al. (1996) reported that there was no significant difference between adult male and female listeners' magnitude estimation judgments of the intelligibility of taped utterances of speech samples by males and females. However, females' subjective impression was that male voices were more understandable and males' subjective impression was that female voices were more intelligible, possibly reflecting personal gender bias. Markham and Hazan (2004) investigated the intelligibility of words recorded by adult males and females and 13-year-old children, as a function of listeners' gender and age (7–8 years, 11–12 years and adult). Listener gender was not a significant factor. Although women were slightly more intelligible than men, the authors argued that the specific acoustic-phonetic characteristics of the individual talker were the more likely determinant of the outcome. The gender interrelationship of the talker and listener was not statistically significant. In contrast, Ericson and McKinley (1997) reported that in quiet, female talkers tended to mask each other more than male talkers and mixed gender pairs.

An unexpected finding was that listeners performed significantly better in the Bison noise than in quiet by 7%. Our previous studies have shown that a noise background can either have no effect or be detrimental to speech understanding, depending on the SNR and the spectrum of the speech relative to the noise (Abel et al., 1990; Abel et al., 2012). An analysis of order effects revealed that the outcome was possibly due to the lower average percentage of hits for the quiet conditions when they were presented before the noise conditions. When the noise conditions were first, the average percentage of hits for the quiet conditions was higher, although the difference was not statistically significant. The pattern of outcomes suggests that the apparent beneficial effect of the noise may have been the result of practice rather than enhanced intelligibility.

It was also found that the percentage of hits was significantly higher for the male right target talker than for the male left and female target talkers whose percentages of hits were not different from each other. This could be the result of differences in speech clarity or accent. Care was taken to select recordings from among the four available male talkers that sounded similar. Spectral analysis of the speech waveforms from the three talkers at the left and right ears confirmed that they were similar from 250 Hz to 8 kHz (see Figure 5). Small differences in measurement in the order of 5 dB were likely due to right-left differences in the placement of the earphones of the headset on the manikin head (Paquier et al., 2012). At the speech frequencies, 500 Hz to 4 kHz, the level of the Bison noise was either at or below the level of the speech. The possibility that ear dominance accounted for the higher percentage of hits for the male right talker is discussed below.

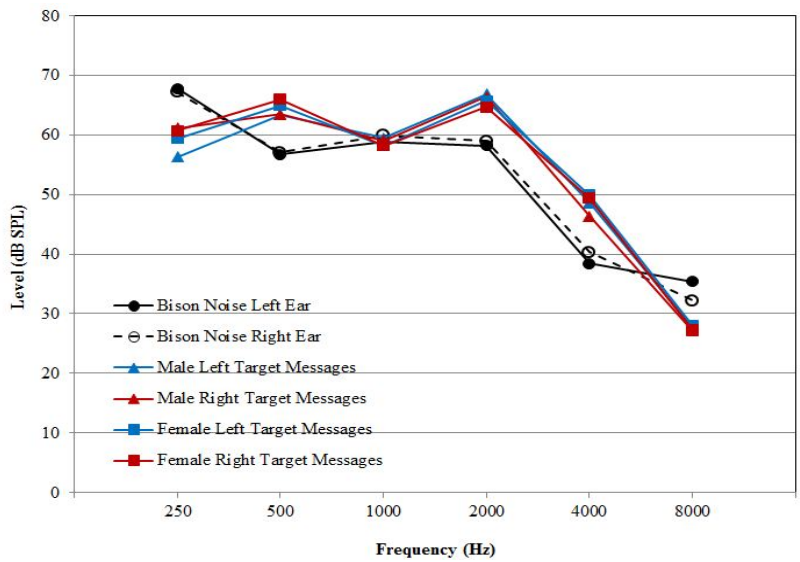

Figure 5: A comparison of the energy spectra for the target messages and the Bison noise, separately for left and right ears.

One of the questions of interest was whether the ear assignment of the female talker, left ear or right ear, would affect listeners' ability to correctly respond to target messages delivered by the three talkers. It was expected that there would be a relative advantage for the male talker who was not accompanied by the female talker. The results showed that, indeed, when the female was assigned to the left ear, the percentage of hits was significantly greater for the male right talker than for either the male left talker or female by 25%. However, when the female talker was assigned to the right ear, the percentages of hits were similar for the three talkers, ranging from 77–81%. This pattern of results was the same for each of the components of the message i.e., the ear, gender, colour and number, taken separately. The attribution of right-ear superiority to explain the outcome is supported by the finding that the percentage of hits was also relatively greater for the female target talker when she was assigned to the right rather than the left ear. These findings point to a right ear advantage in processing speech that corroborates previous research on right ear dominance in right-handers (Foundas et al., 2006; Kimura, 2011). It also supports the conclusion that the dominant right ear is better than the left at discriminating among messages. The outcome suggests that higher priority messages should be delivered to the right ear of right-handed operators.

Missed targets and false alarms proved to be relatively rare. Misses were greater than 12% only in the case of target messages delivered by the male left talker, in quiet but not in the Bison noise, when the female talker was also assigned to the left ear. In the reverse situation, the female talker in the right ear, the prevalence of misses was relatively small at less than 4% for the male right talker. This outcome supports the conclusion stated above that, in situations of auditory overload, the right ear would be better at handling overlapping messages from different networks.

Supplementary text (auditory-visual messaging) proved to be beneficial. Listeners achieved relatively, although not significantly, higher percentages of hits when the target talkers were accompanied by text than when they were not. The gain amounted to 26% for the male left target talker, 10% for the male right target talker and 15% for the female target talker. Within each of the associated target talker subgroups, the provision of supplementary text resulted in relatively better performance than no text or random text by 9–15%. Although text improved outcome, the percent correct associated with the talkers who were not accompanied by text never dipped below 62.5%, showing that text for one talker did not result in inattention to target messages delivered by the unaccompanied talkers. The finding of auditory-visual benefit corroborates earlier studies by Grant and co-workers (Grant et al., 1998) on the benefits of combining auditory and visual inputs. It also supports recent findings of the utility of multi-modal communications in command and control environments (Finomore et al., 2011). The outcomes of the present study further suggest the value of adding text consistently for a selected talker, given simultaneous messages from different networks in situations characterized by auditory overload.

6 Conclusions

In answer to the questions posed at the outset, this study showed that in situations characterized by the simultaneous delivery of audio messages over multiple communication channels, i.e., auditory overload during military operations:

1. Male and female listeners performed similarly, as did listeners engaged in military and civilian occupations.

2. Significantly higher scores found in the Bison noise for a speech-to-noise ratio of 5 dB were possibly due to practice.

3. Averaged across backgrounds, ear assignment of the female talker and text conditions, there was an advantage of 12% for the male talker assigned to the right ear, and a relative advantage of 8% for the female target talker when she was assigned to the right ear. The right ear was also better than the left at distinguishing between talkers.

4. Male and female talkers were equally intelligible.

5. Listeners' ability to understand target messages was relatively greater when text accompanied audio presentations, but only when associated with a selected talker's target messages rather than randomly across talkers.

6. Improvements due to the provision of supplementary text for target messages from one talker did not result in inattention to target messages that were not accompanied by text from either the same or other talkers.

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List of symbols/abbreviations/acronyms/initialisms

ANOVA	Analysis of variance
AV speech	Auditory-visual speech
C3I	Command, control, communications and intelligence
CAF	Canadian Armed Forces
CRM	Coordinate Response Measure
CVC	Consonant-vowel-consonant
dB	Decibels, a measure of sound level
dBA	Decibels, A-weighted; a measure of sound level, weighted to model the frequency response characteristics of the human ear
dB HL	Decibels, hearing level; a measure of hearing threshold, relative to normal hearing
dB SPL	Decibels, sound pressure level; a measure of sound level, relative to 0.0002 μbar
DRDC	Defence Research and Development Canada
HREC	Human Research Ethics Committee
kHz	Kilohertz, one thousand cycles per second; a measure of stimulus frequency
LSD	Least significant difference
MCP	Mobile command post
NSF	Noise Simulation Facility
SNR	Speech-to-noise ratio

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This research determined whether the provision of supplementary text would help resolve the problem of auditory overload during military command and control operations. Listeners, twenty-four English-fluent, normal-hearing, males and females, were presented one block of 78 triads of simultaneous messages over a communication headset, under each of twelve listening conditions. The messages were recordings made by two males (left and right ears, respectively) and a female. Listening conditions were defined by combinations of the background (quiet or vehicle noise), ear assignment of the female talker (right or left ear), and the provision of supplementary text (none, random but equally likely across the three talkers or associated with one of the three talkers). Using a computer keypad, listeners encoded only those messages which began with a pre-assigned call sign. These occurred once during 27 of the 78 triads, nine from each of the three talkers. The overall mean percentage of correct responses was 78%. Male and female listeners performed similarly and were equally intelligible as talkers. There was a significant right ear advantage for discriminating among talkers. Provision of text resulted in an increase in the percentage correct of 10–26% that did not compromise understanding of unaccompanied target messages.

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Speech understanding; competing messages; noise.